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Supplement to September 1971 'Electronics & Power'

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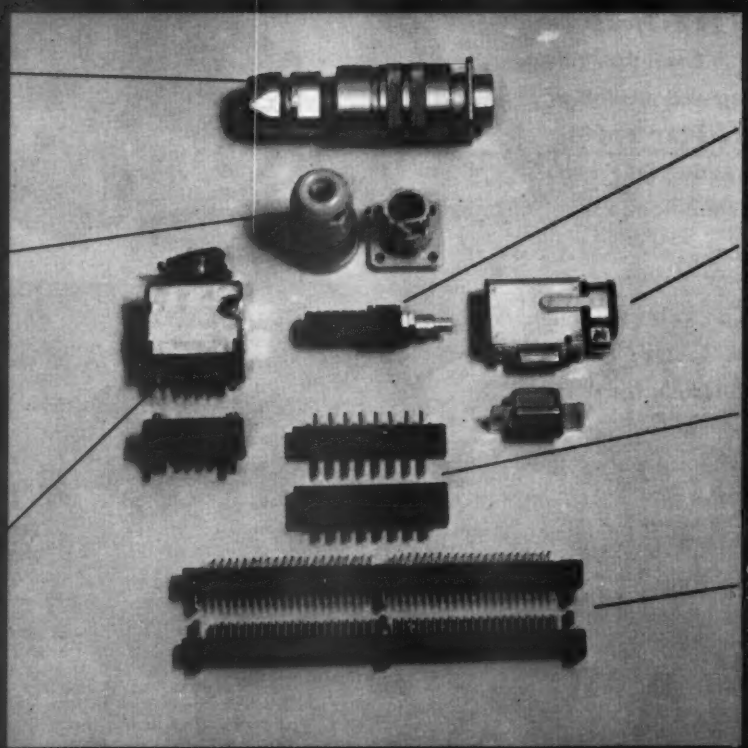

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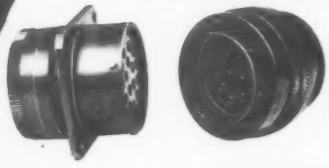

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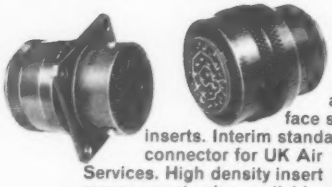

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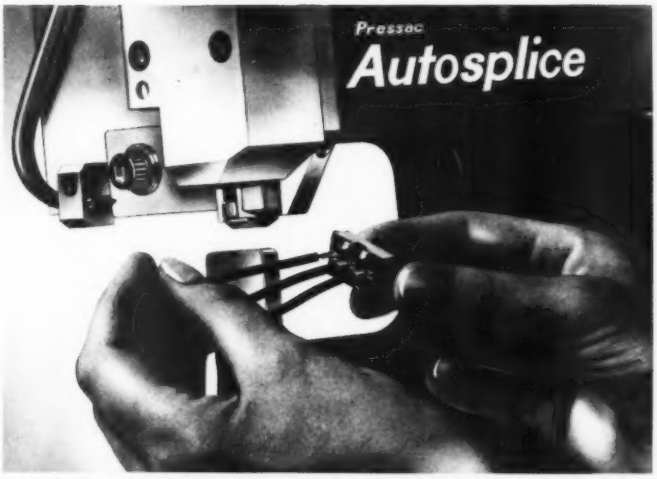

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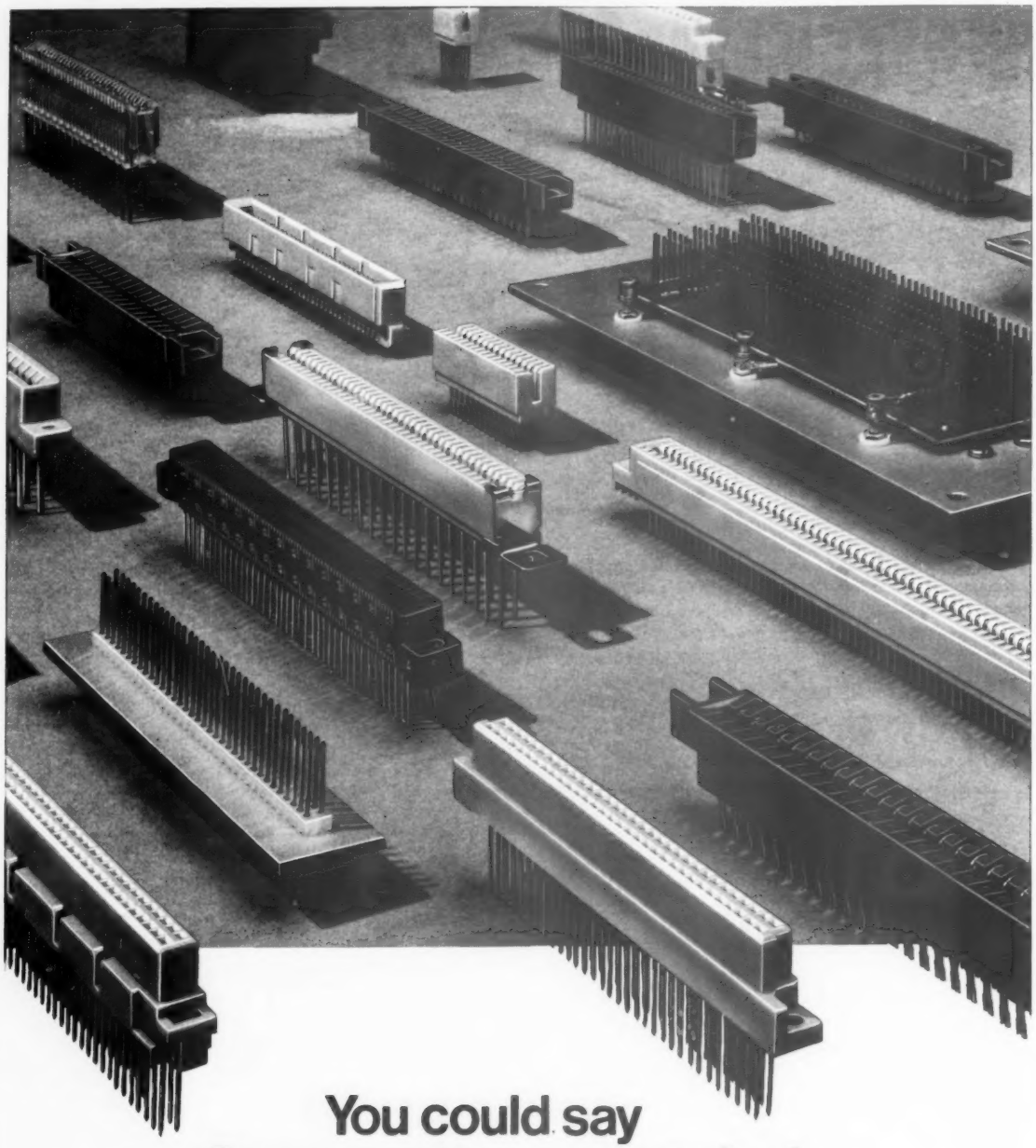

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CONNECTORS IN ELECTRONICS

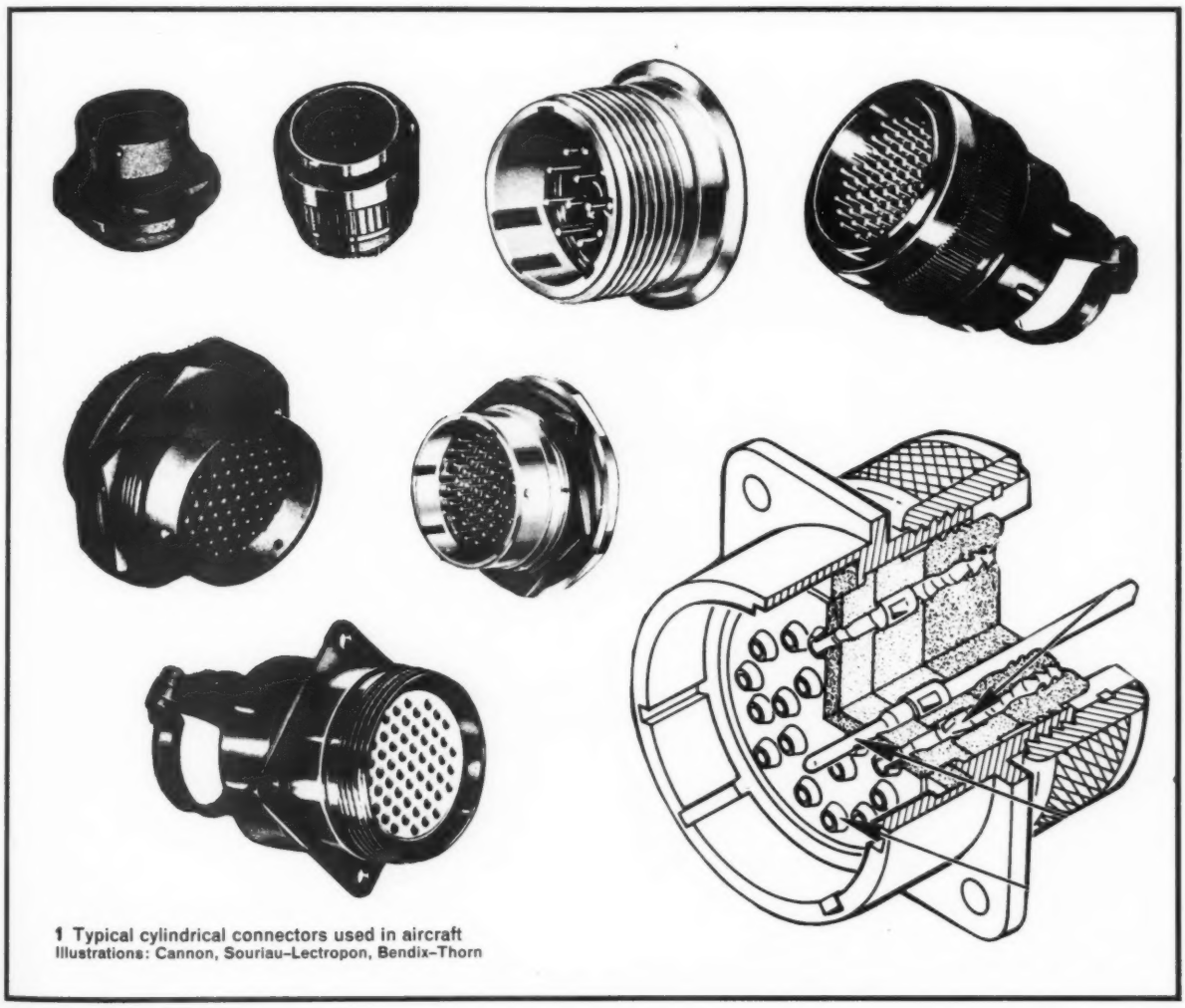
The object of this supplement, the first of its type to be published in *Electronics & Power*, is to review the wide range of connectors in use in many different applications and to indicate how manufacturers are meeting the challenges of increased complexity, smaller size and higher reliability. It is only possible to review certain basic types (one manufacturer alone has over 100000 items in his inventory, of which many are obsolescent and survive only as maintenance items). Types omitted include those for the consumer industry, where price is more important than ruggedness or high reliability; it should not be inferred that such components are unreliable, but as they are used in benign environments they are less likely to cause trouble than those used in the often extreme environments of, say, military vehicles or aircraft.

EXPERIENCE has shown that connectors made for the professional and military markets show little change over a period of ten years or so. During this period, improvements and modifications occur which may be considered as evolution. Every few years, some new idea or approach leads to the development of new ranges which are either smaller, more environment-resistant or sometimes cheaper. Over the past few years, the most drastic changes have probably been in size reduction, the replacement of threaded couplings with bayonet types, the introduction of replaceable contacts crimped instead of soldered to the cables, and improved materials, especially organic types, where the requirement for higher operating temperatures has led to greatly improved dielectrics.

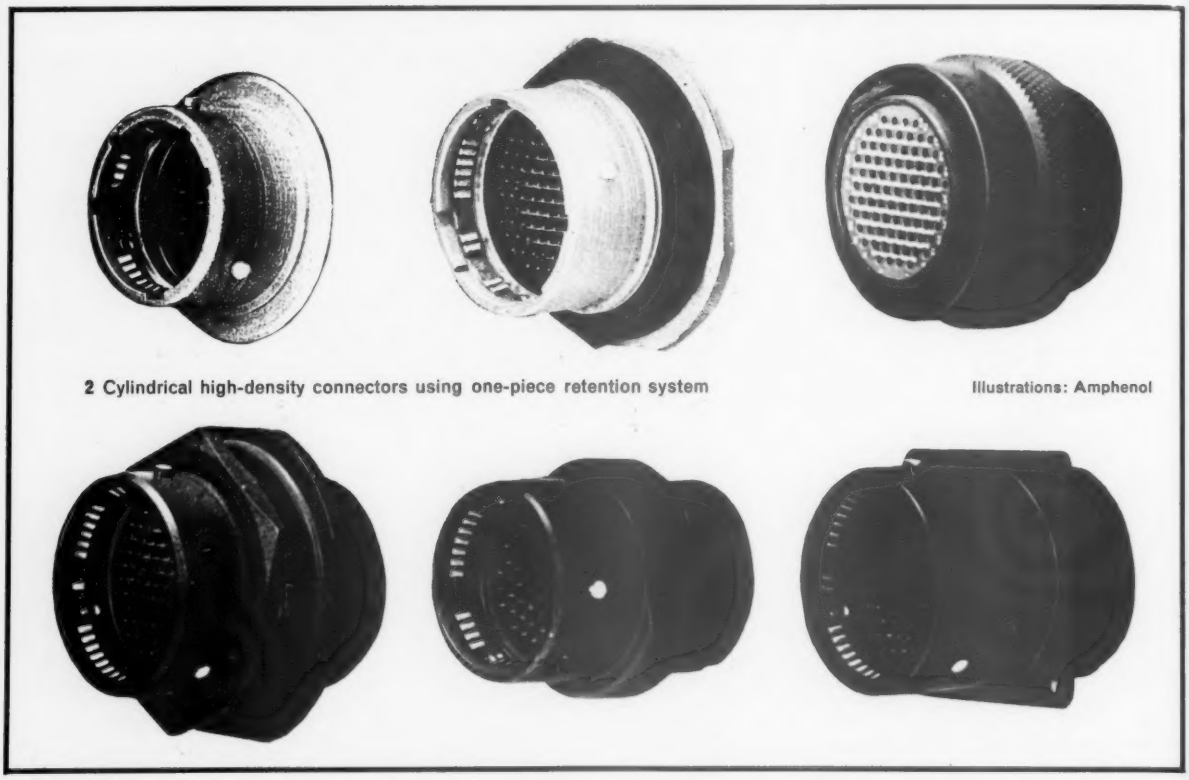
Environments are becoming more severe, and a connector is expected to withstand practically any natural or man-made environment such as heat, cold and moisture in any combination and in rapid succession.[1] Solvents, oils, hydraulic fluids and detergents attack many elastomers and polymers, and new materials are constantly under development to improve their properties in these respects. The maintenance of a good seal under rapidly changing air pressures is particularly difficult, as is the need for low contact resistance and high insulation resistance.

Methods are constantly being produced to test whether the connector will survive, and in many instances these tests are far more severe than any that other components are expected to withstand. A common phrase sums it all up: 'the connector is unprotected'; it is not always put inside a box or chassis like many other components.

The worst case is probably its use in aircraft; for example, on the outside of a Navy helicopter it is submitted to salt spray, heat, cold, jet fuel and deicing fluids, as well as shocks, bumps and vibrations.



1 Typical cylindrical connectors used in aircraft
Illustrations: Cannon, Souriau–Lectropon, Bendix–Thorn



2 Cylindrical high-density connectors using one-piece retention system

Illustrations: Amphenol

Obviously not all connectors have to survive such severe conditions, and those used to connect printed-circuit boards into an equipment have entirely different constraints put on them.

Classification

It is possible to classify low-frequency connectors into five main groups, as follows:

- multiway cylindrical types, both threaded and bayonet coupling, which are lightweight and are primarily intended for use in aircraft or avionics
- heavy-duty cylindrical types intended for heavy-current supply to military vehicles
- rack-and-panel connectors, used to connect boxes of equipment into chassis or racks in airborne and other equipment
- printed-circuit connectors
- miscellaneous types, for test sockets, plug-in relays, integrated circuits etc.

Lightweight cylindrical connectors

As these connectors are largely used in aircraft and avionics, most of the new materials and processes first appear in this category where the continual demand is for improved performance, greater reliability and reduced size and weight. With reduction in size has come the need to make up cables and contacts separately rather than solder them *in situ* as was the practice a few years ago. The crimped removable contact has made it possible to make connectors with about 100 'ways' in a shell of approximately 1in diameter. It is possible to inspect and test each contact before assembly, and risk of damage by overheating with a soldering iron is eliminated.

Bayonet coupling allows quick and easy removal of connectors—especially valuable in cramped conditions in an aircraft—and accidentally unmating due to vibration is unlikely; the only real disadvantage is that shell-to-shell continuity is not as good as with threaded types.

When contacts are small, as in size 22 (0·04 mm), they can become bent during maintenance. To overcome this problem, shells are available with a so-called 'non-scoop' facility, but they are usually longer and heavier.

One-piece contact-retention systems (Fig. 3) require a rather special organic material to form the insertion disc, which is used to retain all the contacts at once rather than individually as in the earlier and more common design using metal clips.

There is disagreement about the relative merits of front or rear insertion and release of removable contacts. Both systems have their advantages and disadvantages, and it is desirable to institute a rigid training system for maintenance of either type with strict control over tools, contacts, cable etc., if the designed reliability is to be maintained after servicing or modification.

The trend to higher density of contacts within a given shell size seems to have reached its logical limit, and it is difficult to foresee how higher densities can be achieved in connectors.[2] The problem is no longer one of insulation over a small gap and the danger of breakdown at relatively high voltage; it is a problem of handling and purely mechanical factors (such as wall thickness of insulators, strength of pins and the intricacies in contact formation), combined with low contact resistance.

Cylindrical heavy-duty connectors

These connectors are used to connect military vehicles carrying communication systems, radar etc., and must withstand rough handling (including the possibility of being run over by a heavy vehicle) as well as exposure to all weathers and climates. They must be easily unmated in conditions of extreme cold and with hands made clumsy by heavy gloves. Originally the shells were made from brass or gunmetal, but recently the use of nylon has drastically reduced cost and weight while still giving an extremely robust product.

In the United States, one design of connector is made to a specification which calls for 'on-load circuit breaking' at currents of up to about 300 A. This specification requires special contact metals and an arc-rupturing device which does not cause permanent damage to the insulation; it also requires special test equipment. In the United Kingdom, there has so far been no demand for this type of connector, and it is normally considered that the 'switching of current' is not a job for connectors, and that they should not be carrying current when broken. A study of contact phenomena will show that different problems are encountered with contacts unmated in the 'live' and 'dead' conditions.

Too little attention has been paid to the problems of cables and connectors in combination. Obviously, they must be made for each other, and a recent study has shown that the new UK metric range of cables can be connected by crimping without any loss of reliability. This point is important, as the relationship of crimp-contact barrel, tool and cable must be carefully controlled if a reliable joint is to be made.

Rack-and-panel connectors

In these connectors, one part mounts on the chassis or frame and the other on a cabinet or rack. In one variation, the 'free' part is contained within a housing and attached to a cable or harness. Those which consist of mouldings without a protective shell are suitable for environments where they are not submitted to rough handling.

The metal-shell type is available in many styles, including some known as 'environment-resisting', which usually means that they

turn to p. S10

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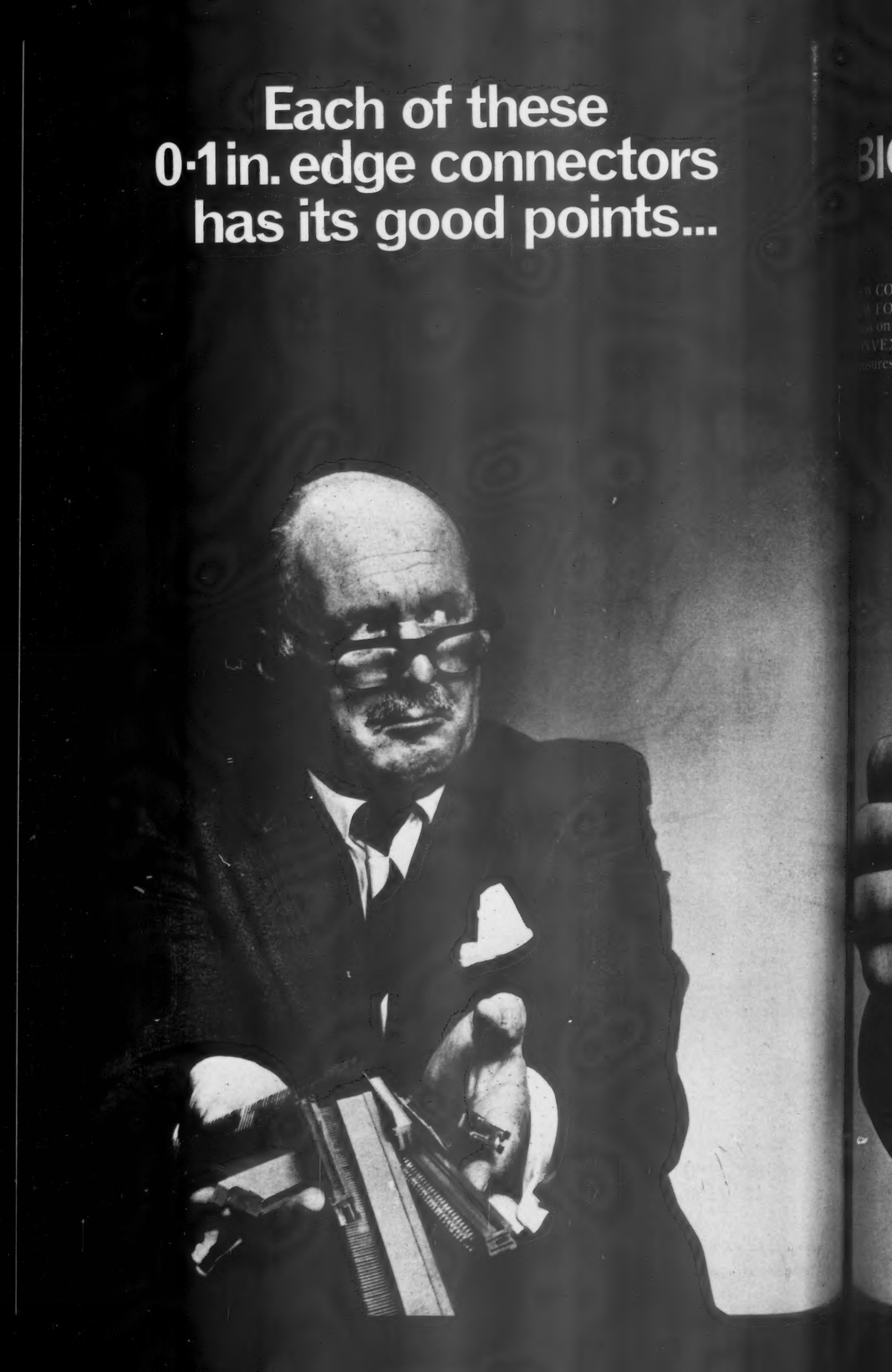

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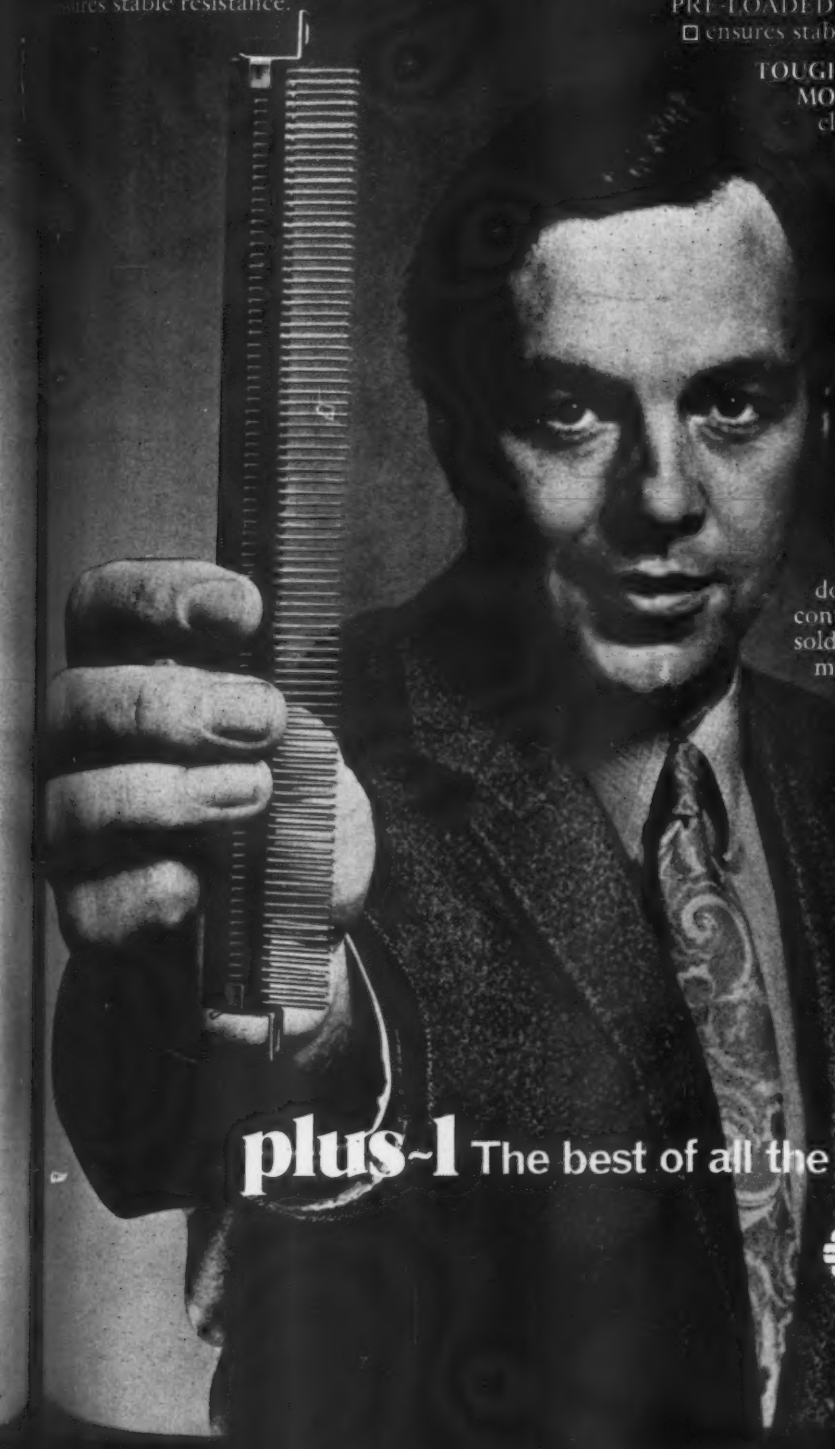

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continued from p. S6

are sealed against climatic conditions and perhaps air pressure. There are now versions having crimped removable contacts; they can be made very small, as it is no longer necessary to use a soldering iron for cable connections.

As with some cylindrical types, a combination of screened and unscreened contacts is available under the generic name of 'hybrid' connectors; this type is particularly useful when, as is often the case, both current and signal leads must be brought from within the cabinet or chassis to the outside world. If this type of connection is used for r.f. circuits, care has to be taken to check on its voltage standing-wave ratio, as many such components are intended only for pulse transmission where screening, but not exact impedance matching, is needed over a wide frequency band.

A problem is encountered with the rack-and-panel type of connector when it is mounted at the back of an equipment and must be mated 'blind'. Tolerances on the shells or dowels, which also act as polarisers, may not allow two different makes of similar connector to make good contact, particularly in depth. Even when the same make is used, this point has to be watched, and special care is needed whenever ready removal of the box of electronics is essential to avoid expensive downtime.

Developments in this type of connector have been towards reduction in size and pitch of contacts, which can be as low as 0·637 mm. It seems unlikely that these dimensions will be reduced further because of handling difficulties rather than lack of material technology.

This type of connector is also extensively used for cable-to-rack connections, and the locating dowel or dowels may also provide a locking device to prevent accidental disengagement as well as mismating.

Printed-circuit connectors

This type represents possibly the largest quantity group of any in the entire connector range. Printed-circuit connectors are often custom-built for particular equipment, especially computers. Tooling costs are nothing like so high as for the multiway cylindrical connectors, and computer manufacturers are able to place substantial orders over a fair period of time.

There are two basic types: one-part connectors, which use the printed board as the male portion; and two-part types, where the male half is attached to the board and the female half to a chassis, card frame or 'mother board', which forms part of the equipment assembly. The connectors are not 'sealed' or environment-resistant, and are all available in a variety of different numbers of ways at various pitches.

For many years, the standard contact pitch was based on a decimalised fraction 0·156in, but gradually the standard grid pitch of 2·54mm and its subdivisions have made headway, and the majority of connectors of recent design are based either on 3·8 or 2·54mm with a minority at 1·27mm (which calls for very accurate manufacture and placement of tracks). A further variation with a pitch of 3·2mm is now coming into use in the computer industry. Higher densities can be achieved by using more than two rows of contacts, and some connectors of this type are specially designed for use with multilayer printed-circuit boards.

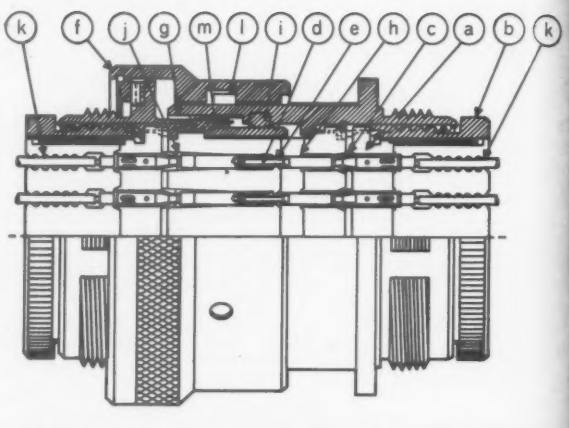
With one-part connectors, tolerances have to be maintained on contact spacing as well as thickness and length. Often, not only are the two mating halves made by different companies but they are also made of different materials—the socket from diallyl phthalate or some other plastic moulding and the plug from epoxide-resin glass cloth. Differing expansion rates and shrinkage on aging can result in failure to separate after many hours in use in hot equipment.

The one-part socket connector can be used for single- or double-sided boards, and contacts are broadly of the 'bellows' or so-called 'tuning-fork' types. The latter type generally gives much higher insertion forces, and is perhaps more likely to damage a board through its lower elasticity. Terminations for both types of contact can now be obtained for crimping, soldering or wire wrapping.

For many years, the onus has been with the printed-board makers to ensure that the boards mate with connectors, but it is very difficult to maintain close control over flatness, bow and twist when the printed pattern is of a variable nature. The worst case is where all the copper is removed from one side of the board (clearly with single-sided boards) and most of it remains on the reverse side. Modern copperclad laminates have eased this situation, but it is still difficult to ensure mating unless both board and socket are closely specified by the designer.

The use of two-part connectors is on the increase; it is easier to ensure mating under adverse conditions, and it is simpler than having the printed 'plug' half made independently of the socket. These connectors are used in two ways—to join printed boards to wiring harnesses and, more recently, to join them to a 'mother board', which may be a large multilayer board forming the whole or part of a central computer system. This 'mother board' is connected

turn to p. S12



3 Internal construction of Amphenol cylindrical high-density connector showing 50% 'no-scoop' design

a Moulded one-piece contact-retention disc
b Captive rear-locking nut
c Individual contact risers
d Anti-scoop recessed pin contacts (in receptacle)
e Closed-entry socket insert and contacts
f Captive triple-bayonet coupling system
g 5-key polarisation
h Interface mating seal
i Dynamic O ring peripheral shell ring
j Monoblock construction; inserts bonded to shells
k Self-sealing rear grommets
l Visual mating indicator
m Shell-to-shell earthing fingers

4 Rack-and-panel connectors; (*a*) Cannon and Amphenol; (*b*) McMurdo type with d.c. and r.f. contacts

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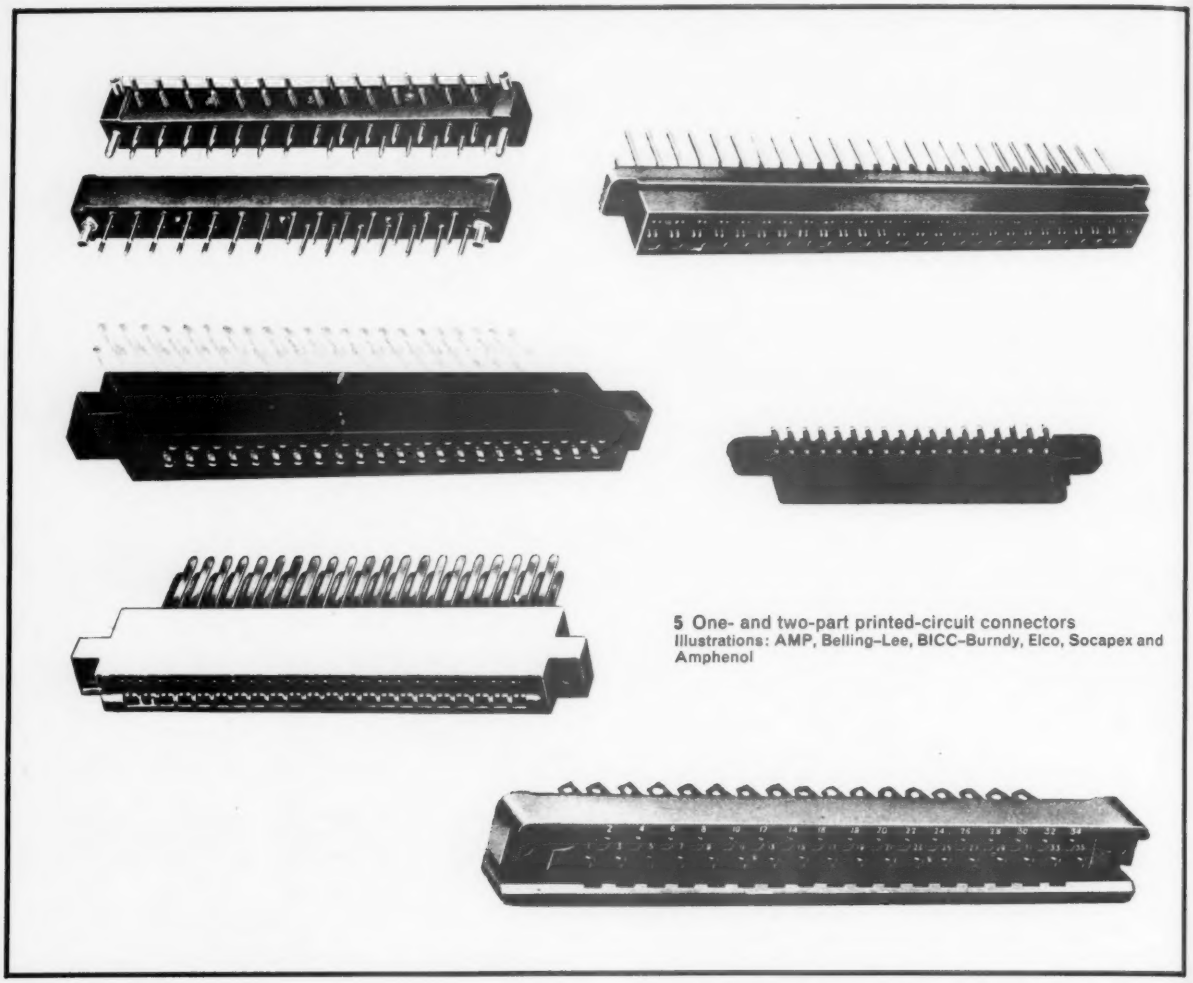

5 One- and two-part printed-circuit connectors
Illustrations: AMP, Belling–Lee, BICC–Burndy, Elco, Socapex and Amphenol

continued from p. S10

to the wiring harness. Various forms of back-plane wiring systems, both automatic and manual, are changing what was a complicated process into one which can be numerically controlled and thus free from error.

There is no easier way of repairing failures on printed-circuit boards than by unplugging them from the equipment, but one is then left with a 'dead' board to which connection must be made temporarily to diagnose the fault. Various forms of jigs and cords have been made for this purpose, but with modern high-speed integrated circuits it may not be permissible to extend the lead length in this way.

Another disadvantage of these connectors is the loss of space which could be used by active circuitry; a way around this problem is to use integrated flexible 'tails', which emerge directly from a multilayer board and fasten on to suitable terminations; they allow the board to be swung away from the equipment for servicing while still 'live'.

With new and larger forms of integrated circuit, with more 'components' on one chip (as in medium- and large-scale integration), there will be less need for the 'mother/daughter' board connectors unless the complexity of the equipment advances at a faster rate than at present.

Miscellaneous connectors

Connectors for 'plug-in' devices are of many types, and of growing importance are those used for the insertion of dual-inline packages for integrated circuits, which may be monolithic or hybrid types packaged in plastics or ceramics and with leads designed for insertion into printed-circuit boards.[3,4] Originally, this type of socket was used for 'breadboarding', but there seems to be a trend towards greater use in equipment on a permanent basis.

Sockets of this kind allow quick replacement of integrated circuits without the otherwise difficult and sometimes costly method of desoldering with vacuum soldering irons or specially made multihead irons. With desoldering, there is risk of damage to expensive printed-circuit boards, and with multilayer boards the damage may go unseen, causing disastrous failure in service. There is a continuing need for easy replacement, and for fault finding the age-old way of replacement by another component dies hard. Aircraft applications particularly require a quick turnround, and ease of replacement without loss of reliability is vital to the operator. Although the first uses of integrated circuits were in applications where space and weight saving was essential (as in aerospace), they have now come down so much in price that they are being used in consumer goods such as television and radio sets, 'hi-fi' systems, electronic organs etc. Plug-in devices are attractive in this area, where quick and easy replacement is essential.

A basic problem for the integrated-circuit maker is of what metals to make the leads. With hermetic packages, a material which matches the inorganic glass or ceramic is essential if a seal is to be made, which calls for alloys such as 29% Ni; 17% Co; 54% Fe or 42% Ni; 58% Fe.[5] Devices packaged in moulded plastics must use a different alloy to match the high expansion rates of the organic materials. Despite difficulties in stamping, nickel is the most favoured, although cupronickel and some clad metals are also being used.

Certainly, the problems of thermal matching, conductivity, compatibility with the silicon device, environmental resistance and ease of working are paramount to the integrated circuit manufacturer. The need to make the lead into a satisfactory plug is quite a different question, and has not been examined in any detail. Leads to these devices are both flat and round in section, according to the manufacturers' choice, and receptacles for these are in some cases made to accept either style of contact. A tighter specification for lead size, finish and quality than exists at the moment is desirable, so that these leads could perform as satisfactory 'plugs'.

Relay receptacles are still largely fitted with solder-type non-replaceable contacts, but where these have to be fitted into an aircraft wiring system (as distinct from inside a 'black box'), there are several types made with insertable, crimpable contacts similar to multiway connectors.

Terminal-junction integrated wiring system

The rapid increase in the complexity of electronic and electrical equipment has led to a large number of different methods of

turn to p. S14

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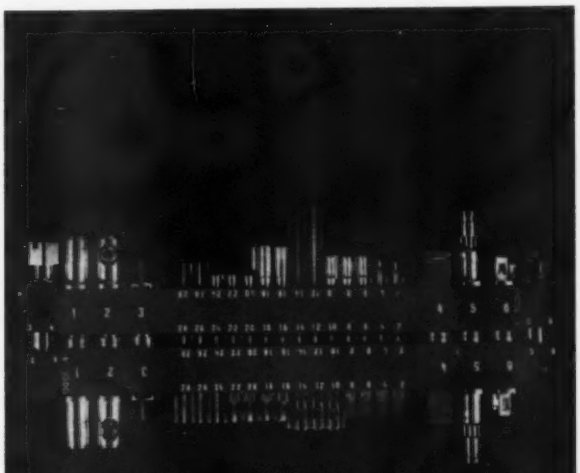
Technical data

Working voltage	250V. D.C./A.C. r.m.s.
Rated current per contact	3 Amps
Contact resistance	3 milli-ohms max.
Total contact resistance	10 milli-ohms max.
Insertion force per contact	0·6N typically.
Endurance	500 insertions and withdrawals.
Coaxial unit – standing Wave ratio at 1000 MHz	1·12 (used with 2mm PTFE insulated coaxial cable).
Mouldings	Glass filled diallyl-phthalate.
Guides	Nickel plated brass. Stainless steel available to special order.
Polarising	*701* Two 6 position plug-in guides giving 36 combinations. *701CX* Two 4 position plug-in guides giving 16 combinations.



The 701 Series connector illustrated is designed to show the range of terminations

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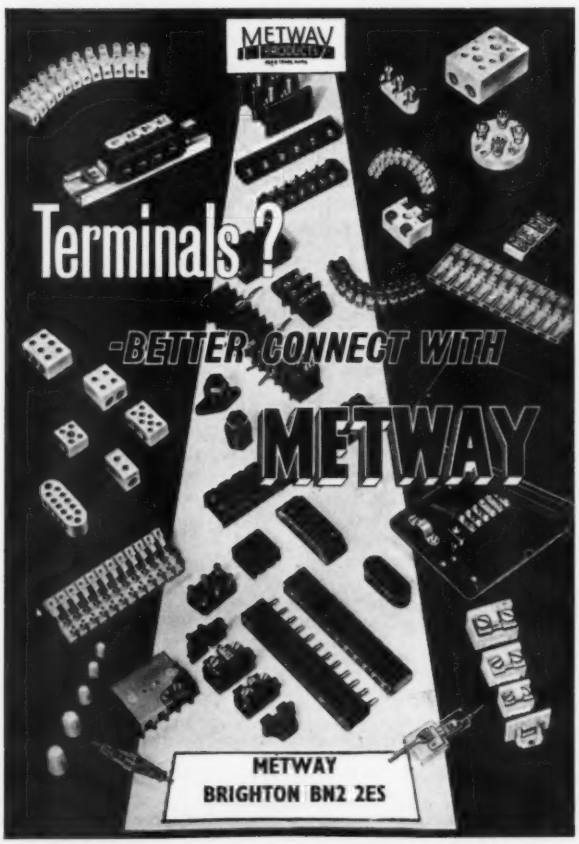

continued from p. S12

connection to cables as well as to components. In civil and military aircraft, the situation has become serious, and the use of crimped joints, in itself an improvement on soldering, has led to the need for many different sizes of tool—each expensive, easily damaged and not easy to identify. The result is that it becomes too easy to crimp a joint with the wrong tool, which can lead to disastrous failure.

At bulkheads in ships and in aircraft there is a need for junctions of some kind, and connectors are used for this purpose as well as junction boxes. So-called 'bussing' arrangements have been used for many years, but more recently several schemes have been suggested for rationalising the whole wiring system in aircraft to use one system of jointing, at the back of connectors, to relays, switches and any other components which are mounted externally. This approach would eliminate differences in training programmes for installers and servicemen, and would reduce the number of tools to a minimum.[6]

There are many technical problems, one of which is that some of the male contacts used in high-density connectors are too fragile when used in a 'bussing' system. Another problem is concerned with the different approaches to rear or front release of contacts, where it is a matter of opinion as to which is preferred in maintenance.

Future developments

Looking into the future in the fast-moving electronics industry is an extremely hazardous business, but the radical changes brought about by the increasing use of integrated circuits must be reflected in the components used with them. Printed-circuit boards have developed into complex multilayer circuits with small holes and track widths, and many more components can be mounted on a given-sized board than in the past. Although there may be fewer interconnections between boards (especially as large-scale and medium-scale integration grows more available), many more connections will be needed to external systems or components.

Voltages and currents are lower than in the days when valves were used, but reduction of interference and crosstalk is still needed. Multiconnectors incorporating filter pins or true coaxial contacts are becoming more important in some strategic equipment, where it is vital to reduce or eliminate stray radiation. As a result, multicontact connectors are also being produced with screen clamping at the rear and multicontact fingers on the shells, to provide good electrical screening over all the connector when shielded multicore cables are used.

Ease of servicing and modification is high on the list of needs of the Services and civil-aircraft users. A reduction in the number of different tools used for making crimped joints is needed now to reduce the possibilities of unreliability caused by the using of incorrect tools. International standardisation could do much here.

Many of these things will improve by evolution in time, but it is perhaps worth looking to see if there is any other means of making 'connections' without actually using 'connectors'.

One approach might be the use of optoelectronics to transfer signals without actual physical contact. A solid-state lamp and a photocell can 'communicate' without actual contact, and an array of such devices could conceivably replace a multiway connector. The elimination of rubbing contacts, insulation and all other well known failure mechanisms common to connectors might well compensate for the apparent complexity involved.

An alternative approach is by the use of multiplexing, where by frequency-conversion or pulse-code-modulation (p.c.m.) techniques many different signals can be passed along one pair of wires.[7] The availability of integrated circuits has made p.c.m. an attractive proposition and one which is being tried experimentally on some civil aircraft.

Ribbon cables, with either flat-foil or stranded circular conductors, have now been in production for some time, but few attempts have been made to provide special connectors for them, and the use of such cables has undoubtedly been restricted in consequence. A new family of connectors made especially for the more common types of this sort of wiring seems to be a very necessary requirement, and the new types of two-part printed-circuit connectors now being envisaged might be adapted for this purpose.

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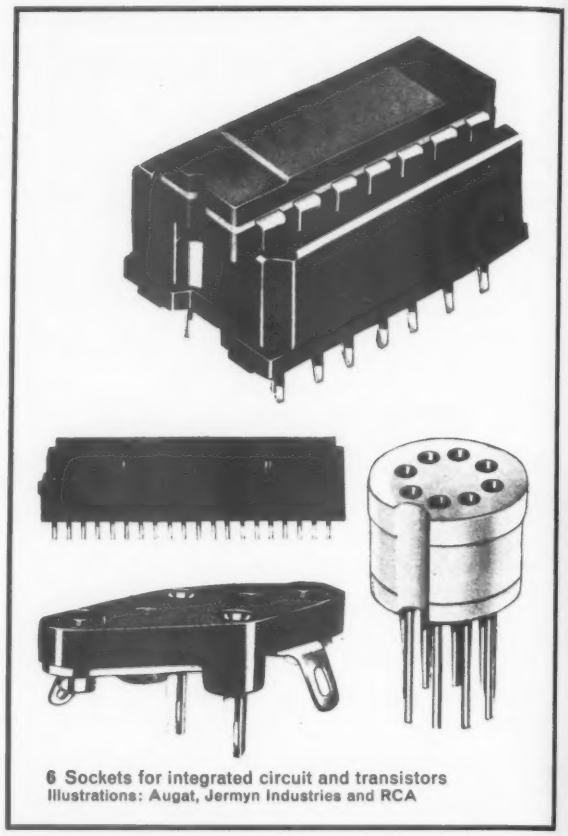
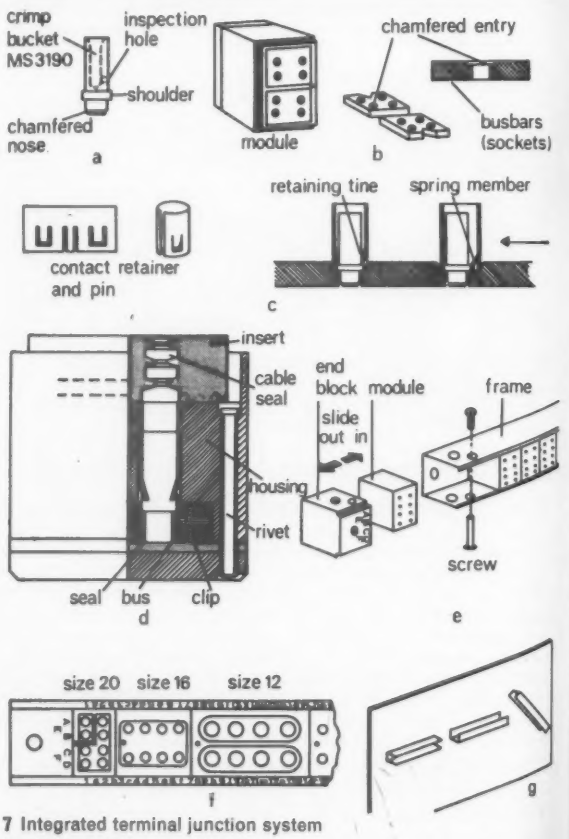
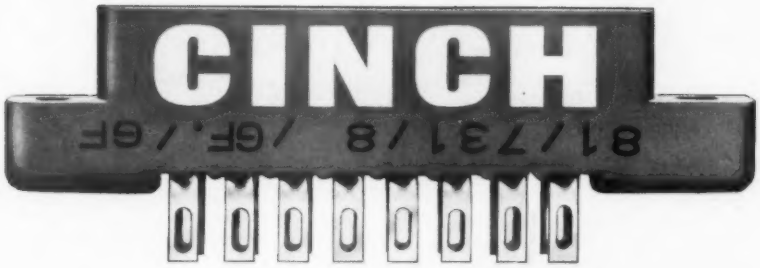


6 Sockets for integrated circuit and transistors
Illustrations: Augat, Jermyn Industries and RCA



7 Integrated terminal junction system
Illustrations: Hellermann-Deutsch
a Rear-release crimped contact; NAS 1600-style pin
b Passive 'bussing' arrangements
c Retention principle
d Module assembly
e Complete TJ/JF unit
f Interchangeability of modules
g Versatility of mounting



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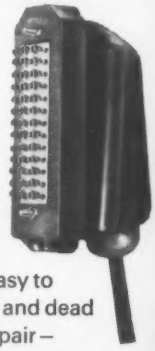

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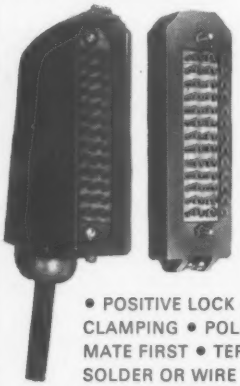

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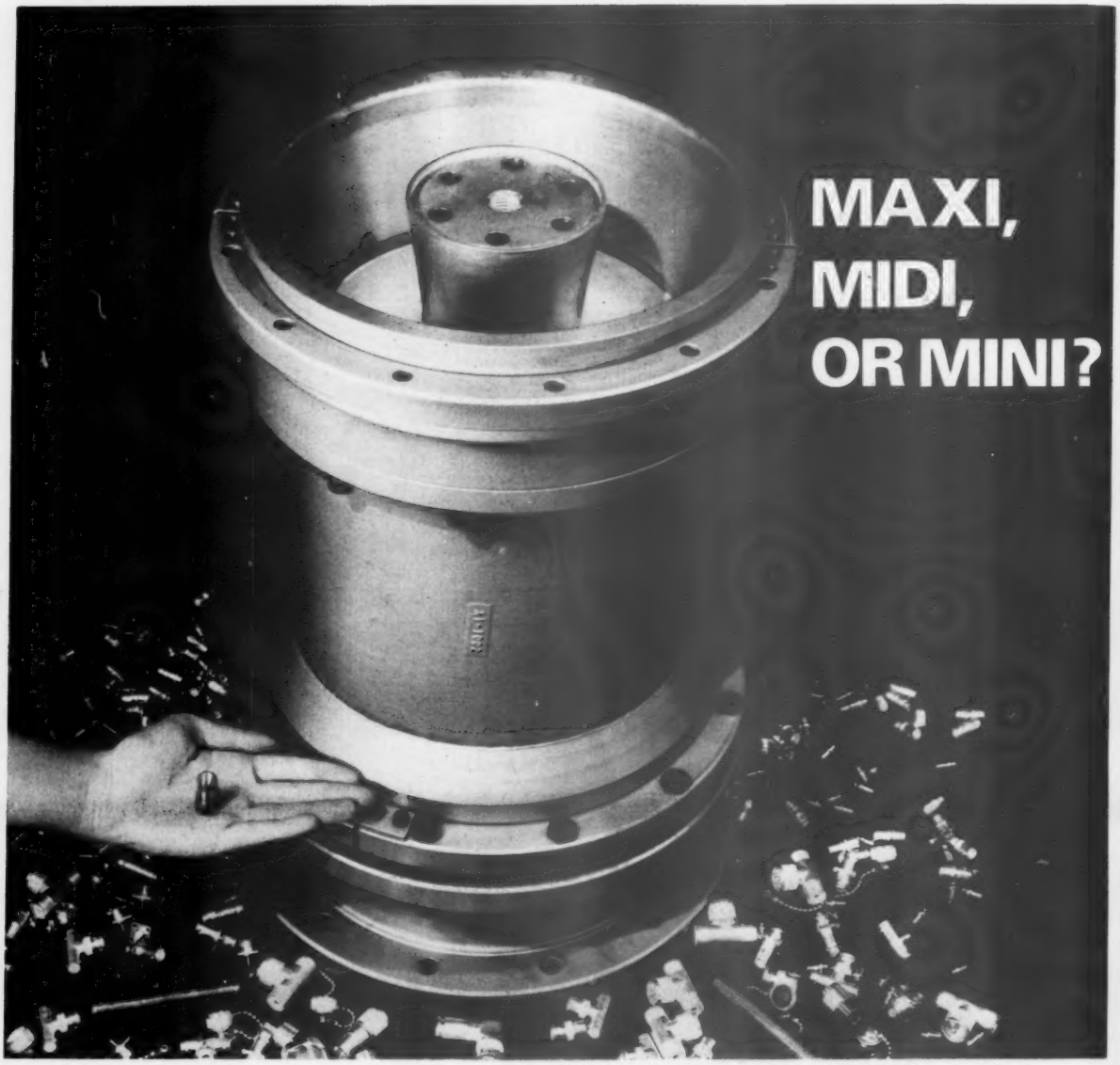

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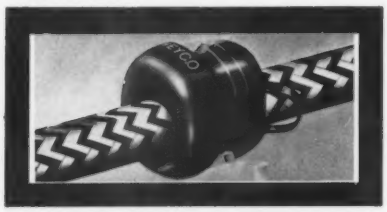

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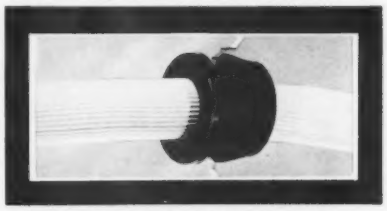

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